ON THE WAVE EXCITATION IN THE TURBULENT METEOR TRACE

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The solution to the problem of excitation of longitudinal and transverse electromagnetic waves in randomly inhomogeneous media is reduced to the derivation of a complex effective dielectric constant (EDC) tensor which non-locally connects together the average values of field and current. When speaking about the average macroscopic electromagnetic fields in continuous media, we imply that the field values which are rapidly fluctuating on a microscopic scale in space and time become smoothed out in a specified way due to the inhomogeneous mixing of diffusion.

Mean field longitudinal wave propagation in a turbulent, incompressible plasma flow of cold electrons, with the perturbed values of electron density and velocity changing both in space and time, has been investigated in the hydrodynamic approximation, (GAVRILENKO and JANDIERI, 1981). A model describing the polarization in terms of a continuous dispersing medium consisting of a set of homogeneously distributed electric dipole-oscillators with random natural frequencies changing both in space and time is suggested in JANDIERI et al. (1986). Proceeding from the derived general expression for the EDC tensor new modes of longitudinal and transverse electromagnetic wave generation due to fluctuation in the parameters of the medium has been predicted. In this connection, it is of interest to investigate the peculiarities of electromagnetic longitudinal and transverse wave propagation in such randomly inhomogeneous media where, apart from the charged particle concentration change, the random spatial and temporal changes of natural frequency of closely located oscillators take place.

Suppose the inhomogeneous "system" possesses a natural oscillation frequency ω_p prior to the passage of a body with a finite mass. After the meteor passage through the spatial region under consideration, the system becomes excited and begins to oscillate with a frequency which is, in the general case, a random fluctuation of spatial coordinates and time

$$\Omega^2(\vec{r}, t) = \omega_o^2 + \gamma^2(\vec{r}, t) \tag{1}$$

The latter term γ^2, leads to a temporal polarization change and to the generation of longitudinal and transverse electromagnetic waves in the inhomogeneous turbulent meteor trace.

The initial system for the solution of the given problem is a closed one consisting of the electric field strength wave equation and the equation of a harmonic oscillator with randomly varying natural frequency $\Omega(\vec{r}, t)$:

$$\text{rot rot } \vec{E}\,(\vec{r},t)\, \frac{1}{C^2}\; \frac{\partial^2\vec{E}}{\partial t^2} = -\, \frac{4\pi\cdot\partial\vec{j}}{C^2\partial t}$$

$$\ddot{\vec{S}}(\vec{r},t) + \Omega^2(\vec{r}, t)\,\vec{S}(\vec{r}, t) = \frac{e_q}{m^*}\,\vec{E}(\vec{r}, t) \tag{2}$$

$$\vec{J}(\vec{r}, t) = e_q\,N(\vec{r}, t)\,\dot{\vec{S}}(\vec{r}, t)$$

where e_q and m^* are the oscillator "effective" charge and reduced mass, $\vec{S}(\vec{r}, t)^q$ is the "effective" charge displacement from their equilibrium positions, $N(\vec{r}, t)$ is the density of dipole-oscillators formed due to positive and negative "effective" charge displacements from their equilibrium positions by the local electric field $\vec{E}(\vec{r}, t)$ and $\vec{j}(\vec{r}, t)$ is the polarization current density.

Following the usual procedure of the perturbation method, we represent all the values as a sum of two terms - an average plus a fluctuating one. If it is further assumed that the perturbed parts (considered as small) of fields and currents are characterized by zero averages so that

$$\begin{aligned} \vec{E}(\vec{r}, t) &= <\vec{E}(\vec{r}, t)> + \vec{E}_1(\vec{r}, t) = \vec{E}_1(\vec{r}, t) \\ \vec{S}(\vec{r}, t) &= <\vec{S}(\vec{r}, t)> + \vec{S}_1(\vec{r}, t) = \vec{S}_1(\vec{r}, t) \\ \vec{N}(\vec{r}, t) &= <N> + N_1(\vec{r}, t) = \vec{N}_1(\vec{r}, t) \end{aligned} \tag{3}$$

To find the EDC tensor of the randomly inhomogeneous medium under consideration, we use Kaner's method (KANER, 1959), while restricting ourselves to a case when the perturbed parts vary with time according to the harmonic law $\sim e^{-i\omega t}$.

In our further analysis of the derived EDC tensor, we use a correlation function having a Gaussian form $B(\rho) = e\,\exp(-\rho^2/\ell^2)$, where ℓ is the characteristic correlation radius of fluctuations of the frequency term $\gamma(\vec{r})$ and the electronic density of oscillators $N_1(\vec{r})$.

For the case of large-scale inhomogeneities, the full electromagnetic wave propagation in inhomogeneous medium is considered, its properties being described by an effective permeability $\varepsilon_{ij}^{eff}(\omega, k)$. When the excited transverse wave frequency is close to the oscillator natural frequency ω_o, the solution of the transverse wave dispersion equation $k^2 = \omega^2/C^2\cdot\varepsilon_{eff}^{tr}(\omega,k)$ results in two roots of the refractive index

$$n_{1eff}^{tr}(\omega) = \left(\frac{k\ell}{k_o}\right)^2 \simeq \frac{\omega_p^2}{\omega_o^2 - \omega^2}\,, \quad n_{2eff}^{tr}(\omega) \simeq \frac{3}{4}\,\omega_p^2\,\frac{\omega^2 - \omega_o^2}{<\gamma^2>} \tag{4}$$

the first of them describes an ordinary transverse wave in the vicinity of the resonance (zero approximation), while the second takes into account the characteristic peculiarities of the inhomogeneous medium. Here ω_p stands for plasma frequency.

The longitudinal part of $\varepsilon_{ij}^{eff}(\omega, k)$ may be calculated in a similar way. By solving the dispersion equation for longitudinal waves $\varepsilon_{eff}^{\ell}(\omega, k) = 0$, we may show that in the long-wave approximation, when $k_\ell C/\omega_p \ll 1$

$$\omega^2 = \Omega^2 - \frac{1}{3}\frac{\omega_p^2}{(\Omega^2 - \omega^2)^2}\left[\langle\gamma^2\rangle - 2\frac{\langle N_1\gamma\rangle}{\langle N\rangle}(\omega_o^2-\omega^2) + \frac{\langle N_1^2\rangle}{\langle N\rangle^2}(\omega^2{}_o-\omega^2)^2\right]\left(\frac{K_eC}{\omega}\right)^2 \tag{5}$$

where $\Omega^2 = \omega_o^2 + \omega_\rho^2$, $k_\ell^2 = k^2(1 + 1/k^2\ell^2)$ is the new "effective" wave number. Assuming that $N_1 \cong 0$, we obtain the previously obtained result of JANDIERI et al., (1986). With $\omega \simeq \omega_o$, i.e. in the vicinity of the resonance, the density fluctuation contribution to the longitudinal wave excitation is negligibly small as compared with the frequency fluctuation. Taking into account absorption by means of formal substitution $\omega_o \to \omega_o - i\,J/2$ where J is the frequency correction for the attenuation of the oscillations of the oscillators proper, it may be easily proved by denoting real values of the wave vector $\vec{k}_e$ and complex frequency $\omega = \omega' - i\omega''$ that the expressions for the group velocity and attenuation of propagating longitudinal waves are as follows:

$$\vec{V}_{gr} = \frac{\partial k_e\omega}{\partial k_\ell} = -\frac{1}{3}\frac{\langle\gamma^2\rangle\,\vec{k}_e}{\omega_o k_o^2\,\omega_\rho^2} \tag{6}$$

$$\text{Im}\,\omega = \frac{1}{6}\,J\,\frac{\langle\gamma^2\rangle\Omega^2}{\omega_o^2\,\omega_\rho^4}\left(\frac{k_e}{k_o}\right)^2 \tag{7}$$

Thus, we may conclude that in this case, the excited longitudinal waves are attenuated along the group velocity direction, the latter being anticollinear to the vector $\bar{x}$ direction.

According to (5), the presence of a correlation between the fluctuations of the charged particle density and the natural oscillation frequency, far from the resonance frequency, may change the direction of the excited longitudinal wave group velocity with respect to $\bar{x}$, even to the extent of reversal. The latter may occur when the dispersions of the density and frequency fluctuations may turn out to be smaller than $\langle N_1\gamma\rangle$. These relationships are valid only in case of weak absorption. Clearly, such plasma oscillations are characterized by dispersion.

The derived relationships may also be used to solve the inverse problem. By measuring the frequency and the wavelength of the propagating waves, we may obtain the characteristic scales of the fluctuations of the randomly inhomogeneous turbulent medium parameters.

References

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